What is the Value of Knowing the Value of Water?

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Abstract

There is cross-sector consensus that clean water is important and provides value to society, but the data shows that stated clean water values often do not result in clean water actions. Despite decades of research measuring and elevating the economic and social values of clean water, water value information has yet to be incorporated into mainstream decision-making; this qualitative value of information study seeks to understand why. I conducted semi-structured interviews across private for-profit, private non-profit, and public state government organizations throughout Minnesota in order to learn more about how these institutions consider water value information in their work and to discern the factors that determine the utility, relevance, and influential power of water value information in diverse decision-contexts. I found that all sectors acknowledge the importance of clean water and recognize its value, but that awareness of clean water value does not always lead to actions that consider water quality due to different competing priorities within each sector. I learned that no single type of water value information has blanket utility for any sector, but rather the utility of different types of information depends on the decision-context and the accessibility, ease of use, and credibility of the information. Water value information is most useful for raising awareness and setting priorities, not for accounting, and the more we can give meaning to data and information, the more useful it is. Issues of capacity, resources, relevance to existing decision frameworks, access to information, and scale of information are the greatest barriers to use; the most urgent needs to overcome these challenges are increased collaboration between water valuation researchers and decision-makers, creation of finer scale information, and improved communication about the stories behind water value information. My findings illuminate the shortcomings of water value information and highlight where and how future water valuation efforts can be more influential in decision-making.

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Introduction and Background

Clean water is essential for human well-being: it supports a wealth of ecosystem services and in turn is extremely valuable to society (1-2). A large body of research has emerged over the past few decades with the goal of elevating the value clean water provides to society through more explicit measurement and accounting of the various ecosystem services it supports (1-7). This scholarship has assigned monetized values to clean water using economic tools such as cost-benefit analyses and contingent valuation studies (3-7); compared both use and non-use values of clean water (1, 3, 5, 7, 9, 10); and considered the power and influence of policy mechanisms designed to protect clean water values (1, 8). This work has taught us about the various dimensions of clean water value—clean water is valuable because it supports public health, anchors economies and businesses, provides recreation opportunities, and holds spiritual and cultural significance (1-7)—and established direct linkages between actions, water quality, and benefits to society (2), which form the basis of water value information.

The theory behind this water valuation research matches that of the ecosystem service paradigm (Figure 1): produce models and tools that are generalizable and easy to use that generate information on the value of ecosystem services and that value information will incentivize institutions to take actions and inform policies that safeguard our natural capital (11-16, 19). Water valuation research grew out of the desire to encourage greater investments in water resource protection by raising awareness about the benefits clean water provides to society and translating clean water values into water value information: language that has meaning and significance for diverse decision-makers because it connects changes in water quality to changes in human wellbeing (1-4, 6, 8-9, 11-12). Water valuation scientists ascribe to the definition of value adopted by economists in the ecosystem services community: "value" is a measure of worth, but not just monetary worth, relative and sociocultural worth as well. Therefore, water value information consists of monetary metrics of water value which estimated the economic values of water protection, prioritization metrics such as maps that show biophysical and socioeconomic risks to water or measures of trade-offs between different decisions, quantitative social science data on public perceptions and opinions about water values

and water resources, and qualitative narratives and stories about clean water value (Figure 2).

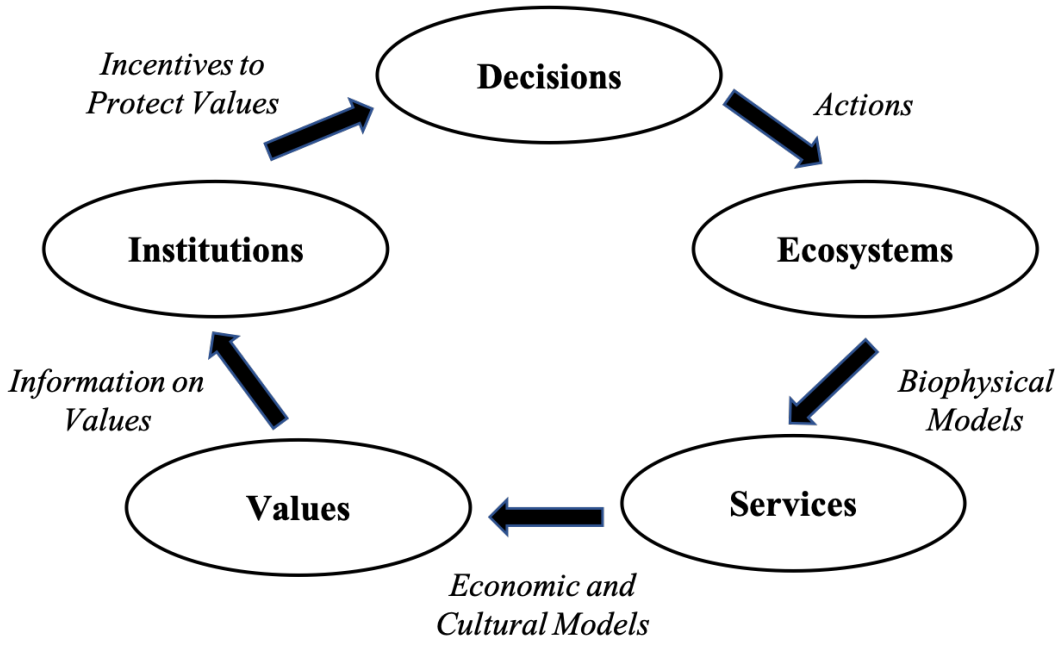

Figure 1 Integrating Ecosystem Services into Decision-Making Framework; Adapted from *Daily et al. 2009, Frontiers in Ecology and the Environment* (12). This theoretical framework posits that instilling information on ecosystem service values into institutions will incentivize decision changes that are protective of ecosystems and the services and values they provide to society.

There is minimal research that addresses whether or not water value information is actually used in decision-making. A recent body of research demonstrates that ecosystem service information has yet to be incorporated into mainstream decision-making (11-19), causing me to infer that the same might be true for water value information. Although the ecosystem services approach has yielded many successes, the ecosystem services community acknowledges that the use of ecosystem service information in decision-making remains relatively uncommon and is therefore resulting in less impact on conservation outcomes than ecosystem services scientists had hoped (11-19). Researchers posit that this is because the ecosystem services tools available simply do not meet the needs of many decision-makers (14, 19), perhaps because the practicality of ecosystem service information is still limited due to the complexity of the

choices decision-makers face (14) or due to systemic prioritization of short-term gains preventing ecosystem service information from being relevant in diverse decision contexts (11, 15).

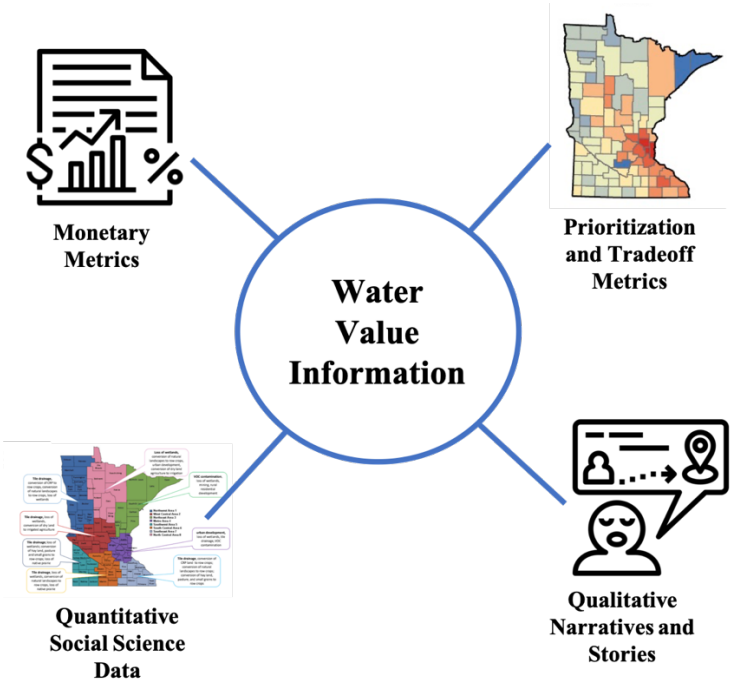

Figure 2 *Types of Water Value Information* Water value information consists of any quantitative or qualitative information that connects changes in water quality to changes in human wellbeing. The four main types of water value information are depicted here: monetary metrics, prioritization and tradeoff metrics, quantitative social science data, and qualitative narratives and stories.

In response, recent studies have analyzed cases of successful incorporation of ecosystem service information into decision-making, specifically in the policy arena, to see how it was used and what made it successful in these decision-processes (17), which use pathways resulted in greater impacts on ecosystem services (17-18), and what characteristics of ecosystem service information increased the likelihood of impact (16). These studies define impact as the ability to encourage actions and changes in decisions that lead to increased protection of ecosystems services and tangible improvements in human wellbeing as a result (16-18). They concluded that ecosystem service information has less impact when used conceptually (to raise awareness, change perspectives, or deepen understanding) compared to when it is used strategically (to build support for protective actions or mediate differences) or instrumentally (to generate action, establish

decision-making processes that consider ecosystem services, and produce measurable outcomes) (17). Although they showed that ecosystem service information has been used successfully in all of these pathways, they found that it is less commonly used instrumentally because this use pathway is the most time and resource intensive.

If the goal of ecosystem service information is to have positive impacts on ecosystem services, but the use cases that have the most impact are too complex to occur with regularity (17-18), the ecosystem services community needs to consider if the benefits of this complexity are worth the costs or if there are ways to reduce the complexity without sacrificing the potential for impact (14). Value of information research, which studies the utility, relevance, and influence of information on decision-making, suggests that information is valuable if the benefits that result from decisions based on that information are greater than the costs of using that information (20). If the complexity of ecosystem service information prevents it from being used in ways that can generate significant benefits to ecosystems, or worse, prevents it from being used at all, it begs the question, what is the value of ecosystem service information?

This research asks that question through the lens of water value information. Despite advances in water valuation, we do not yet understand how institutions consider clean water value in their work or know what types of water value information are most compatible with the existing decision frameworks used by target audiences. We do not yet know how, let alone if, decision-makers use this information, and if decision-makers are not using water value information in decisions, we do not yet know what factors prevent them from using it. Which leaves me wondering, is water value information valuable information? And, if it is not yet valuable, how can we make it valuable?

Conceptual Framework

My research expands on the ecosystem services theory that links information on ecosystem service values with decision-making by adding observations from studies of ecosystem service information use (11-19) and incorporating the premise of value of information ideology (20). In my conceptual framework (Figure 3), I start with the idea that decisions and actions lead to changes in water quality, which result in changes in the

provision of water-related ecosystem services, and, in turn, cause changes in the value of water resources (2, 12). I define water value information in my framework as any quantitative or qualitative data or understanding about the relationship between actions and clean water value (21). My framework diverges from traditional ecosystem services theory because I believe that there is a fork in the link between water value information and decision-making: I argue that water value information does not always incentivize changes in decisions, but rather it only leads to changes in decision-making if it is easy for decision-makers to use in their work.

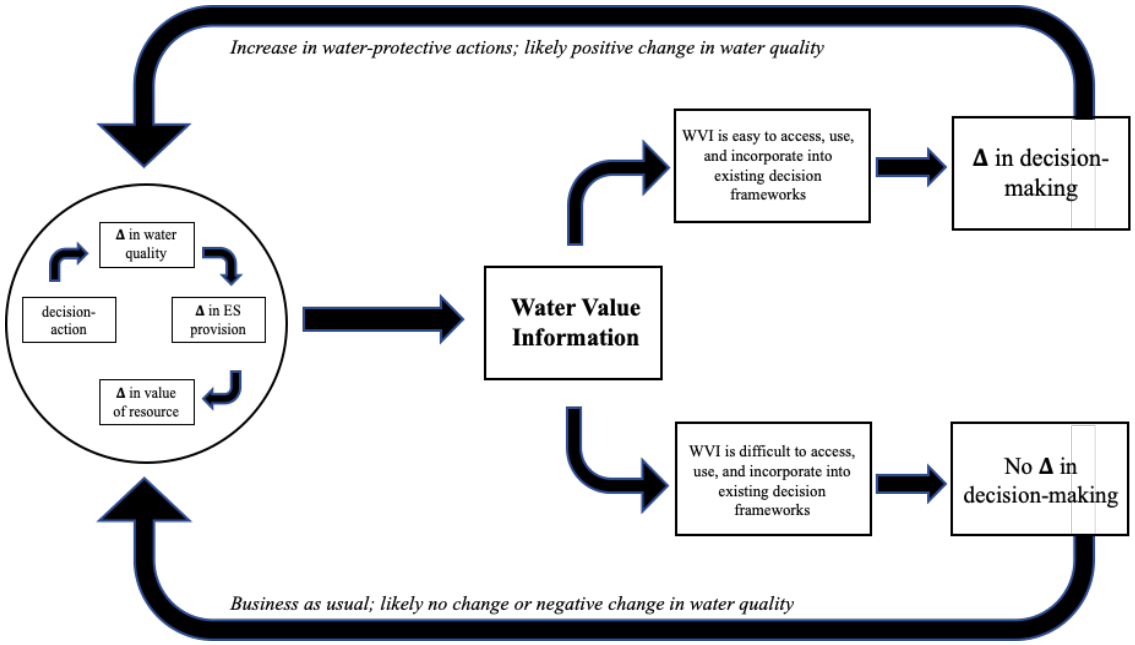

Figure 3 Value of Water Value Information Framework: Water value information (WVI) is any quantitative or qualitative data or understanding about the relationship between actions and clean water values. Water value information leads to changes in decision-making if it is easy to access, use, and incorporate into existing decision frameworks; accordingly, water value information is more valuable if it leads to changes in decision-making that result in increased water-protective actions (top path). If water value information is difficult to access, use, and incorporate into existing decision frameworks, it is less valuable because it is less likely to lead to changes in decision-making and therefore less likely to result in the protection of water resources (bottom path).

I contend that water value information is only valuable information if it encourages decision-makers to deviate from business as usual practices and take actions that protect clean water. However, we do not yet know what factors determine which path water value information will take because we do not yet understand what makes water value information easy or difficult for decision-makers to use or how to increase the influential power of water value information in diverse decision-contexts. To address these knowledge gaps, I sought answers to the following research questions:

1. How do different sectors consider clean water value in their work?
2. What types of water value information are most useful to different sectors and in different decision-contexts?
3. Where and how can water value information lead to the most change?

Methodology

To better understand the utility and influence of water value information in diverse decision-contexts, I chose to examine the perspectives of decision-makers from private sector companies, non-profit organizations, and state government institutions. Qualitative interviews were an appropriate method for this work because they allow researchers to gain in-depth knowledge about values and decision-making processes with a small sample size (22- 24). I used a semi-structured interview methodology—in which all interviews follow the same protocol of predetermined questions but the interviewer is also allowed to go off script and ask further questions in response to participants' answers—because it focused the work on the views of the participants and allowed for both consistency and flexibility during the data collection process (22-25). I used an iterative workshopping process to create the interview protocol and then carried out pilot interviews to get external feedback on the protocol. The finalized protocol had 12 questions divided into three thematic sections: 1) Institution background and audience; 2) Organizational water values; and 3) Water value information. As part of the protocol, I shared my definition of water value information with interviewees through examples of both quantitative and qualitative types of water value information (Appendix 1).

Data Collection

I chose Minnesota as the geography of interest and Minnesota-based organizations as the study population. I defined private sector companies as "any independent organization that operates to make a profit," non-profit organizations as "any independent non-governmental organization that operates to further a social or environmental cause or to advocate for a particular view on a social or environmental issue rather than to make a profit," and state government institutions as "any organization that is part of a branch or department of the state government and is responsible for oversight and administration of specific government functions." I used a purposeful sampling technique called criterion sampling in which I selected the institutions from which I wanted to interview decision-makers based on knowledge of organizations within each sector that explicitly work with water or water resources in Minnesota or have

expressed interest in clean water protection or other clean water related issues in the state (25-26). The private sector companies I selected have either made commitments to sustainable growth or use water directly in their production processes and the non-profit organizations I chose have environment and sustainability related missions. The state government institutions I selected were the five major state agencies in Minnesota with water-related mandates together with the state government boards, commissions, councils, and legislators in Minnesota with specific water or environment focused responsibilities. The interviewees from each selected organization were management-level actors within their institutions; I defined "management-level" based on job title and expectations of duties that involve decision-making. I interviewed 15 representatives from the private sector, 15 from non-profit organizations, and 16 from state government institutions.

All interviews except one were conducted in person. Before the interview, participants were briefed about the potential benefits and risks of the study, promised anonymity and confidentiality, and asked if they were willing to be recorded and quoted anonymously in my reporting (25). All except one of the interviews were recorded and detailed notes were taken during each interview. Interviews ranged from 30 minutes to one hour in length.

Data Analysis

The recordings were transcribed verbatim and analyzed with NVivo 12 software (QSR International, 2018). I used a combined approach to create the coding structure to ensure the codebook included codes that were inductive (responsive to ideas and topics showing up in the data) as well as deductive (based on my theoretical framework and research questions) (23, 27- 29). The longform answers typical of semi-structured interviews make it difficult to calculate measures of intercoder reliability and agreement; instead, to consider and minimize biases in the coding structure and data analysis, I worked with multiple coders and used an open coding approach within a multi-stage process to design the codebook using a sample of the transcripts, and then I used the agreed upon codebook to code the full set of transcripts (25, 28-29).

I used the final codebook (Appendix 2) as an interpretive framework for the data analysis (23, 25, 28). I read through all of the transcripts multiple times, assigning codes to passages in the data as I read. Each time I used a code, I was claiming that the specific concept that code represents shows up in an interview and the text I assigned to the code is the evidence to support my argument (23, 25, 28). The codes themselves were not analytical, but instead, they provided structure to the qualitative data that facilitated the analysis: once I had coded all 46 transcripts, I could use the codes to search the data for answers to my research questions.

My analysis is my qualitative interpretation of the data. As I read through and coded the data, I took note of themes, which I used to scan the organized data for insights into my research questions (23, 25, 28). After completing the coding process, I worked backwards and matched codes from the codebook to these themes and ran queries in NVivo 12 for the code combinations that could help me determine if these themes were prevalent or not across the data set and to see if and how the most prevalent themes manifested within each sector. I then took the prevalent themes and grouped them based on their relevance to each of my three research questions to see how the emergent themes from the data converged to inform the following findings (Appendix 3).

Findings

Overall, I found that water value information lacks utility and relevance in many decision contexts. My analysis of the data yielded the following key findings that together shed light on the relationship decision-makers in Minnesota have with water value information:

1. There is a disconnect in each sector between awareness of clean water value and action to protect clean water values: Decision-makers across all sectors acknowledge the importance of clean water and recognize its value, but they do not always consider clean water value in their work. Recognition of clean water values can encourage changes in decisions, but competing priorities more consistently prevent clean water values from influencing decision-making.

2. For all sectors, the utility of water value information is contingent upon the accessibility, credibility, and relevance of the information rather than the type of information. Water value information framed within contextually relevant stories increases utility for decision-makers across sectors and is most useful in decision-contexts focused on raising awareness and setting priorities.
3. There is cross-sector agreement that water value information needs to be better translated into meaning, be more transparent, require less time and resources to use, and more directly match the scale and scope of day-to-day decision frameworks; to address these needs, decision-makers from all sectors want water valuation scientists to be stronger communicators and more frequent collaborators.

I saw these same themes emerge in each sector; however, I saw differences across sectors in terms of *why* these themes are present. Below, I elaborate on the nuances behind the emergence of each theme for each sector and explain how the above themes helped me answer my research questions.

1. *How do different sectors consider clean water value in their work?*

Decision-makers from all sectors told me that they work to achieve the goals of their organizations and regardless of sector, success hinges on securing the support of their audiences. As a result, decision-makers told me they regularly consider and prioritize their audience's values in decision-making. Respondents from all sectors told me they have multiple audiences whose values they consider in decision-making (Table 1). In the private sector I heard their main audiences are customers, employees, investors, company executives, and also local residents where their factories or offices are based. In the non-profit sector their audiences vary based on the goals of the organization and the geography in which they work; their audiences consist of all groups and individuals that are interested in, affected by, or can have an impact on their mission, with a particular focus on those who can provide funding or opportunities that make their work possible.

When asked to tell me who their audience is, one non-profit interviewee summed this up nicely:

> *We have many audiences. There are the audiences we engage with, there are the audiences we engage with and serve, and there are the audiences we serve. And, of course, those who either fund our work or who have missions that are aligned with our work and who fund partners of ours to do work that is in parallel or complementary to our own. It is really a pretty broad suite of different kinds of organizations at different scales that we work with to try to move the ball forward.*

In the state government sector, I heard from all interviewees that they mainly work to serve the citizens of Minnesota; for some groups I interviewed, they work to make sure they are serving all people across the state equally, while other state government decision-makers are more focused on a specific region, population, or group of voters. However, regardless of whether they work statewide or primarily with a smaller subset of Minnesota residents, all state government interviewees shared that decision-making in this sector happens within an intricate web that requires working with and across agencies and branches of government in order to secure funding and support for their specific goals; therefore, other agencies, the legislature, and the governor's office are also key audiences for this sector.

Private Sector Audiences	Non-Profit Sector Audiences	State Government Sector Audiences
• Customers/clients • Employees • Investors • Company executives • Local residents	• Grantmakers • Philanthropists • Local residents • Policymakers • Landowners • State government decision-makers • Private sector companies	• Citizens of Minnesota • Constituents • Other state agencies and government bodies

Table 1 Audiences by Sector: *Audiences for each sector based on responses from interviewees.*

Accordingly, I heard from all sectors that they consider clean water value in their work in relation to how clean water matters to their audience and how protecting clean water affects other things their audience cares about. Private sector companies consistently acknowledged that outwardly considering their impacts on water quality can

bolster their reputation with customers, employees, and local communities; non-profit and state government interviewees expressed that they consider clean water value in decision-making because it is important for many of their conservation and societal well-being goals and clean water values resonate with many factions of their diverse audiences.

However, I found that an awareness of clean water value and its importance to their work does not always motivate action. Audience values towards clean water do encourage organizations to act to protect clean water value, but other values are also important in decision-making and if these other values conflict with water protective actions, organizations might be discouraged from taking action. I consistently heard from decision-makers that they face competing priorities that prevent water values from having as much influence on decisions as they could, resulting in disconnects between awareness of clean water values and decision-making that prioritizes protecting those values (Table 2).

In the private sector, this disconnect exists because minimizing risk—whether to profits, reputation, or otherwise—is a key driver of decision-making. Private sector interviewees told me that "highlighting different levels of business risk around water" can encourage them to take actions to protect clean water and help them "prioritize acting where water risk is in [their] company," but they mostly feel that water resources in Minnesota are doing well and pose no risks to their business, discouraging them from taking action. One private sector participant shared:

> *Truthfully, the value of water or the cost of water for us is not going to be a driver for our operations or even really our sustainability program. If we had a situation where our water quality or quantity was not adequate, our priorities would shift dramatically*.

Mirroring the power of risk in private sector decision-making is the power of incentives. Because risk is such a high determinant of action in a company, incentives that offset risk can encourage greater action. This interviewee told me that they take small actions that protect clean water value because it bolsters their reputation, but that without incentives that go beyond reputational benefits they are not likely to do much more:

> *Businesses are willing to do some things for reputation without really necessarily getting much except for the pat on the back for it, but to do something more significant than token kinds of things, they need something back.*

When water is cheap and poses minimal risks, that decreases any incentives for businesses to prioritize water. Profit motivation is short term, so as long as private decision-makers do not perceive short term business risks related to water, they are not going to prioritize it:

> *We're still, in terms of big decisions, a financially based company. We don't talk about the water saving first. We talk about the water saving after we know a decision is a profitable venture... just the fact of business is that if you're not able to turn revenue, you're not going to be a business for very long...You look at what water fees are, there's no business person in this world that would look at those and say that those could possibly be reflective of the true cost of water, which will never then lend to a return on investment under traditional accounting systems.*

Even the interviewee who diverged from this theme and told me that they act to protect clean water value just because they care, expressed that there is no business case for doing so:

> *We made a million dollars in stormwater improvements, which again we had no way of justifying that frankly. So, it was more of a heart connection, like a legacy commitment. And I know that doesn't sound like traditional business language, but I don't actually find traditional business language to be very effective and enforcing or encouraging people to invest in water projects.*

Research Question 1 Findings	**Private Sector**	**Non-Profit Sector**	**State Government Sector**
How do decision-makers consider clean water value in their work?	• Consider audience values, business risk, reputation • Act for philanthropic reasons, to bolster reputation, if they can minimize risk • Disconnect: low perceptions of water risk and low business incentives discourage action even when aware of water values	• Consider audience values, interconnectedness of clean water to other organizational goals • Act to protect water value when it helps achieve mission or garner audience support • Disconnect: securing funding is prioritized in decision-making which can decrease ability for water values to guide decisions	• Consider audience values, interconnectedness of clean water to other organizational goals • Act to protect water values when it helps achieve goals, meet mandates, or garner audience support • Disconnect: target-focused mandates and political differences can make it hard to consider value in decision-making

Table 2 Research Question 1 Findings: *Summary of how decision-makers from different sectors consider clean water value in their work based on interviewee responses.*

In the non-profit sector, their work hinges on securing funding from grantmakers and donations from the public:

> *Being a nonprofit, a lot of what drives us is looking to match what people are looking for, whether that's our donors or our partners that we work with, the community we engage with as well as the foundations and so on.*

I saw this audience focus encourage non-profit decision-makers to highlight how their work protects clean water values, but other times I saw it preventing clean water values from guiding decisions. Interviewees told me their dependence on their audience can force them to follow the money instead of making decisions based on how they could best protect clean water value. Sometimes this is because the available funders are focused on a specific region:

> *Unfortunately, in the conservation world, many times you're chasing opportunity rather than a measured approach to addressing a water quality issue. You have to have willing players and partners, and sometimes the willing partners aren't where the greatest impairment is.*

Other times, clean water values just do not connect well to the funding streams or decision-making processes they are trying to influence:

> *Everybody understands the intuitive kind of almost infinite value of water in some of these cases and yet we haven't been able to connect that in quantifiable, monetizable ways that can then catalyze more action. And so many of these other benefits – although really the things that are most valuable about water – are also really hard to connect with some of these funding streams and decision-making processes because they're outside of the market. They're outside of how a lot of these decisions are made.*

In the state government transcripts, I found that the need to meet statutory mandates takes precedence over considering clean water values in decision-making. Many state government decision-makers felt that they cannot adopt a values-based model for making decisions because they need to appear objective and fair and maintain their funding. One interviewee told me:

> *We are an agency that is heavily science driven and we have to be...We have not necessarily invested in developing and exploring and letting our programs be guided by that type of discussion, "what's the value?" because a lot of our efforts are driven by our regulatory and funding constraints. We have certain obligations*

that are based upon our funding and this work isn't something that's necessarily funded and paid for in our current system.

Another shared that although they recognize clean water value and take actions to protect clean water value, they have other mandates that prevent them from prioritizing clean water value all of the time:

We basically are responsible for protecting human health and the environment and water resources...we do care about clean water very, very much, but we also need to make sure we have a vibrant agricultural sector. Our goal is to find a way to do both...We're very sincere and very committed to clean water. Having said that, we're also, for the most part, scientists and technical people, and we're really aware of the science that goes into these decisions and how difficult it actually is in some cases to achieve water quality goals.

I also heard the need to be fair can prevent state government decision-makers from being able to optimize clean water value protection:

We have to spread out our investments across the state so that everybody's getting it. Whether that makes the most return on investment or not. Just because otherwise, we don't get things funded.

Exacerbating the challenge, state government interviewees shared that political differences and the complexities of water issues prevent clean water values from fully guiding decisions. One participant explained:

The complexity of understanding water issues and linking together all of the perspectives, the world views, the motivations, the values, and the political realities [make it difficult] to find ways to take steps forward.

And the temporal scale mismatch between state government term sessions and realized outcomes from clean water value actions can make it difficult to convince state government decision-makers to take significant actions to protect clean water value:

The water issues we focus on tend to be rather short term, issues that the legislature can address in the next session whenever that is. So, not so much long-term, I try to get the legislature to think about long-term things, but that's a little difficult for people to do who only have a two-year window in their seat. The legislature is focused on things they can get done in this session, so issues like groundwater sustainability and the future of our water are more difficult.

All sectors are aware of clean water value and its importance to their work, but the connection between recognition of clean water value and considerations of clean water value guiding decision-making is inconsistent.

2. *What types of water value information are most useful to different sectors and in different decision-contexts?*

I asked decision-makers to tell me about the utility of different types of quantitative and qualitative water value information (Figure 2; Appendix 1, Question 9b) and found that for all sectors, the utility of water value information is contingent upon accessibility, relevance, and credibility, rather than the type of water value information (Table 3).

Factors Determining Utility of Water Value Information	Private Sector	Non-Profit Sector	State Government Sector
Accessibility	• Do we have access to the information or know it exists? • Is the information easy to understand? • Do we know how to interpret the information? • Does it take a lot of time or resources to use?	• Do we have access to the information or know it exists? • Is the information easy to understand? • Do we know how to interpret the information? • Do we have the resources and skillsets on staff to use the information?	• Do we have access to the information or know it exists? • Is the information easy to understand? • Do we know how to interpret the information? • Do we have the resources and skillsets on staff to use the information?
Relevance	• Is it at a scale that matches our decision-context? • Can it fit easily into our decision-frameworks? • Is there a business case for considering the information? • Does it resonate with our values and our audience's values?	• Is it at a scale that matches our decision-context? • Does it resonate with our values and our audience's values? • Does it match with funding streams? • Does it help us know how to have an impact?	• Does it help us know how to meet state mandates and allocate state dollars fairly? • Does it resonate with our values and our audience's values? • Does it help us know how to have an impact? • Is it actionable?
Credibility	• Do we know and trust where the information comes from and how is it generated? • Does our audience trust the information?	• Do we know and trust where the information comes from and how is it generated? • Does our audience trust the information?	• Do we know and trust where the information comes from and how is it generated? • Does our audience trust the information?

Table 3 Factors of Water Value Information Utility: *Factors that determine whether water value information is accessible, relevant, and credible for each sector.*

My data analysis showed that the accessibility of water value information is not only about having access to the information, but also about the complexity of the information; interviewees from all sectors discussed the understandability of water value information as an important factor in whether or not they could use the information. I heard from all sectors that water value information that is simpler, less time and resource

intensive, and processed and communicated in ways that have meaning to them are not only easier to understand, but easier to use and that currently, water value information is often more complex or technical than they can embrace or interpret with the skill sets and resources they have at their disposal. One private sector respondent explained it is often an issue of time:

> *I think part of the big picture problem is that a lot of sustainability leaders like myself, the ones who are not primarily focused on water, are generally aware of the risks and the benefits. But it's not like we have an elevator speech. If we could just arm all of our business leaders with a slide deck that shares the big picture in that way, we'd be much more effective. But instead we just educate them and expect them to develop their own presentations. And none of us have time.*

I heard from state government interviewees that they simply do not have access to the information:

> *In the political realm, we don't pay for subscriptions to peer review journals. So people are actively doing work that is relevant to what we're doing, but it's not available to us.*

And when they have it, they don't have the skill sets to use the information:

> *I think we need training. The majority of our staff come from a biophysical background. They're engineers, they're hydrogeologists, they're sanitarians, and so they do not feel comfortable using social science.*

A non-profit participant told me there is just more information out there than they can process:

> *We don't have the staff available to be able to find the data and interpret the data and understand the data, it's tough. You guys are generating a lot of new stuff. There are a lot of you and I have a staff of four. So, trying to figure out what to pay attention to and digging into stuff to try to learn more from it, I would love to do more of that. But that tends to be the part of the job that we don't have as much time to spend on it as we'd like.*

This sentiment was echoed across sectors. I heard that sometimes the overwhelming amount of information about clean water that is available in so many different places exacerbates issues of accessibility. One private sector respondent explained:

> *As someone who needs or would like to have access to [water value] information, it takes a lot of effort to try to go find it and dig it out and know it's consistent, know that's it refereed and it's accurate. I think what would be valuable is that there was a common source of truth that mapped the quality, quantity, and trends by geography. That, I could see, would be incredibly valuable to different government agencies, and non-profit agencies. I think that if it was – that one common source of truth would be, really, very valuable.*

Interviewees expressed that the relevance of water value information is determined by how well the information matches with their decision contexts and whether it can highlight how to achieve tangible progress towards their goals. I heard from respondents across sectors that water value information that matches the scale and scope of their decision-contexts has greater relevance because it makes it simpler to incorporate the information into existing decision-frameworks and that water value information that demonstrates where and how they can have a positive impact has greater relevance because it responds to decision-making motivations to improve reputations, secure funding, gain citizen support, and minimize risk. Participants from all sectors voiced that the water value information that is available currently is generated at too large a scale to be relevant to instrumental decisions, that a lot of it is "too academic" or "too generalized" to be practical and "actionable", or that it simply does not match with the way decisions are made. One non-profit interviewee explained:

> *Most of the people we work with would say, "Well, what do you mean a state average? It makes no sense whatsoever because in the north we have this, in the south we have that." They would want to have those return on investment measures downscaled. But once you get into the downscaling game and realize that's the proper way to handle things because water resources are by definition localized, then you get into a space where even the relevant metrics would vary from place-to-place and then the values that people place on those also vary from place-to-place. In order to really make progress...you absolutely have to have this spatial kind of disaggregation.*

A private sector respondent told me:

> *This information is the right idea, but it's at too large of a scale. It would be hard to relate this back to the customer experience idea because we wouldn't exactly know if they even understand the land conservation idea, or "A public land*

> *acquisition yields up to $6.00 return on public benefits." What does that mean? It's a little – I mean, the numbers look good, right? But what's public benefit mean? Not everybody's benefit would be the same. From a business perspective, we would want it to be a little more specific to the demographic than just the dollar.*

And a state government participant shared:

> *I'm not sure how to use this considering the scale that I work with. So, I do work with local communities and local farmers, and when you talk conceptually about a return on investment, it doesn't work. They need to know what I can do to make money. How can I survive if I'm going to change my practices? If you can answer that question at the community scale or even at the individual farm scale, you can really influence behaviors, but it has to be extremely practical, and I think a lot of this work is a lot more theoretical. It doesn't get down to the local scale.*

Interviewees also said that one of the greatest barriers to incorporating water value information into many decisions is that people in Minnesota take clean water for granted, society as a whole does not fully appreciate how valuable water is, there is a lack of public awareness about the state of local water resources, the public thinks state water resources are not at risk, and water is still too cheap for there to be a strong business case or political argument for taking significant actions. Due to the barriers described above, respondents from across sectors shared that currently, water value information is most relevant for raising awareness and setting priorities (Figure 4). One private sector interviewee explained:

> *We operate in setting priorities and accounting – like balance sheets, cost-benefit assessments – that's where we spend most of our time. But I think where the most value [for water value information] is, is with creating a common language and shaping minds, raising awareness...trying to help people understand, "This is* why *we would do it this way."*

One non-profit interviewee told me:

> *I think raising awareness is going to be very important over the next several years. I don't think people are connecting to [water values]. There are misconceptions about the quality of our water in the state that we need to work on.*

And one state government participant shared:

I would say that probably the biggest challenge we face is – and this is becoming a common theme – making the invisible visible for people. And some of it is the fact that people take drinking water for granted, but also I think our cultural values and beliefs are so hidden in everybody's everyday experience that we're making choices without realizing it and part of the power of water valuation is to expose or discover those values. So, for example, when we don't get support for our fee, that shows that very practically we don't value safe drinking water and – until we're able to expose or bring that to light – we're going to be making decisions by default, rather than thinking them through as a state or as a culture and making wise decisions that will ensure a better future.

I heard from all sectors that until there is a "cultural shift" and we have a "common language" that is shared across sectors and audiences that emphasizes and recognizes how important clean water is, it will be difficult for decision-makers to regularly use and incorporate water value information into instrumental decision-contexts. To facilitate that shift, interviewees shared that they will use water value information to set priorities when it can demonstrate where they can have the greatest positive impact on water quality with limited resources.

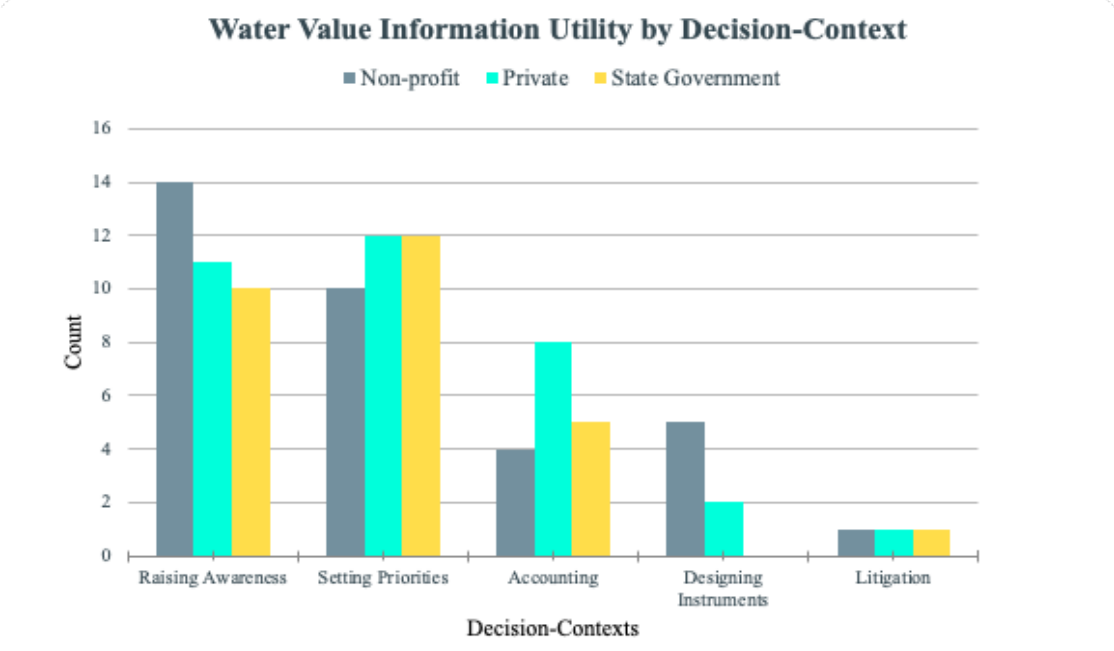

Figure 4 *Total counts of responses for all sectors for each decision-context. All sectors view water value information as most useful and relevant for raising awareness and setting priorities. Respondents defined water value information as "useful and relevant" in this context as easy to incorporate into existing decision frameworks.*

Decision-makers from all sectors also told me that for water value information to be useful in diverse decision-contexts, both the decision-makers and their audience need to trust the information and its source. However, respondents expressed that current water value information is often perceived by them or their audience as not credible or legitimate. I heard it lacks utility because they often do not know what is behind the information, where it came from, or understand how it was generated, which causes them to question the water value information and prevents it from guiding decisions. One state government interviewee shared:

> *I have a healthy skepticism of the metrics you use to get to public benefits. What was the process that you used to get to this? What is the definition of public benefit? I need some information that shows me how you came to this, as opposed to just making a statement.*

A private sector participant told me:

> *I would say the biggest barrier would probably be the validity of the behind-the-scenes calculations into the total value of water. If I come in and I say, "$8.00." Everyone's going to be happy that I've got a number, but they're going to want to know, "Okay, where did you get this stuff from?"*

And a non-profit respondent said:

> *Getting good valuations is key. If you've got good valuations, then you can make determinations based on them. But if you don't have them or you don't trust the valuations you've got, or you know they're flaky, then it's like, is it worth anything? You know? Does it really help me to have a valuation if it's suspect?*

I also heard that even when the decision-makers themselves see water value information as credible and legitimate, if their audience does not trust the information or does not feel that the water value information considers *their* values fully, the water value information is not as useful, as one state government participant explained:

> *I think the lack of recognition of and respect for a lot of what goes on in rural Minnesota by a lot of policy makers and other entities is a big barrier [to using water value information]. A lot of people, they don't understand our values. I*

> *think that the tone of the conversation, I think that the finger pointing at rural Minnesota, at rural agriculture has set the process back.*

Due to all of these factors, I found that water value information is most useful and relevant to all sectors when it is told in story-form. By "story", I do not mean just qualitative narrative water value information, but narratives that use various types of water value information in conjunction — such as qualitative narratives from the audience of interest and quantitative water value metrics — to support each other. As one non-profit participant said, "science information is most useful because it helps build a narrative." I found that for all sectors, the utility of water value information for influencing decisions is contingent on how well the meaning behind it is communicated and who is communicating it. I heard from all sectors that contextually relevant stories are influential in decision-making because they make water value information more accessible, appealing, and credible to them and their audiences. One state government participant told me:

> *The science is one thing, but unless you address the social side as well, you're not going to get people to act on the science. If you just try to tap into people with scientific data, that often leaves a lot of people cold.*

A non-profit interviewee expressed:

> *Stories support our data. There is a big importance of being able to have somebody that is directly impacted on a project, especially when keeping in mind who we are. We are St. Paul-based, metro, Twin Cities, whatever you want to say. We're here. We cannot have the credibility to just kind of go out and tell other people what to do without actually having people that are impacted who are there.*

And a private sector respondent shared:

> *Anytime you can develop tools that communicate and connect at the emotional level rather than just at the intellectual level, it's a lot more valuable in terms of changing behavior.*

Decision-makers told me they want water value information that is less technical, less full of jargon, more contextually relevant, more trustworthy, and that requires less

time and resources to use and digest. Interviewees want water value information that is smaller scale, more focused on impacts, and in the form of contextually relevant stories because then water value information would match more closely with their decision frameworks, be easier to understand and use, have more credibility with their audiences, and help them raise awareness and set priorities.

3. *Where and how can water value information lead to the most change?*

For water value information to be more influential and lead to changes in decisions and increased actions that protect clean water values, interviewees told me these challenges and barriers need to be addressed. Respondents from all sectors expressed that successfully addressing all of these challenges hinges on improving communication and collaboration pathways between water valuation scientists and decision-makers (Figure 5).

One private sector interviewee shared:

> *I very much think that there's – in this society right now – there's this ivory tower view of academics or even just scientists in general. They come off as condescending. "They know more than us" or they have – And so they start to get into this, "They have some alternative agenda." I think we've got to figure out how to bridge that gap better and I don't know – again, it's out of my realm – I don't know if it's politics or just society in general, but I know that scientists do not communicate and relate well to the general public and that's a challenge.*

A non-profit respondent told me:

> *I think that in order to have good science, we have to have open science. In order to have open science we have to have inclusive science, and inclusive science is participatory science.*

And a state government participant explained:

> *We want to continue bringing [water value information] into these watershed processes and projects, but it does take a lot of energy and time and some money to do it. We've worked with the university and others to help us, who are more expert at it than we are, and that's been beneficial so we're going to want to continue to do that.*

Interviewees told me that strengthening communication and collaboration pathways can: help them break down the complexity of water value information that exists and make it more accessible, increase the credibility and legitimacy of water value information by making them a part of the process so they understand how it is generated, allow decision-makers to tell water value information scientists directly what would be most relevant for their decision frameworks in terms of scale and impact, and can help them figure out the best ways to frame and communicate water value information back to their audiences to get them to care.

The data shows that water value information rarely meets all of the necessary utility criteria outlined in the previous section; often, it meets one or two, making it useful in conceptual decision contexts such as raising awareness, but interviewees from all sectors echoed that water value information needs to simultaneously be accessible, relevant, and credible to be used consistently in decision-making and incorporated into strategic and instrumental decision-contexts (Figure 5).

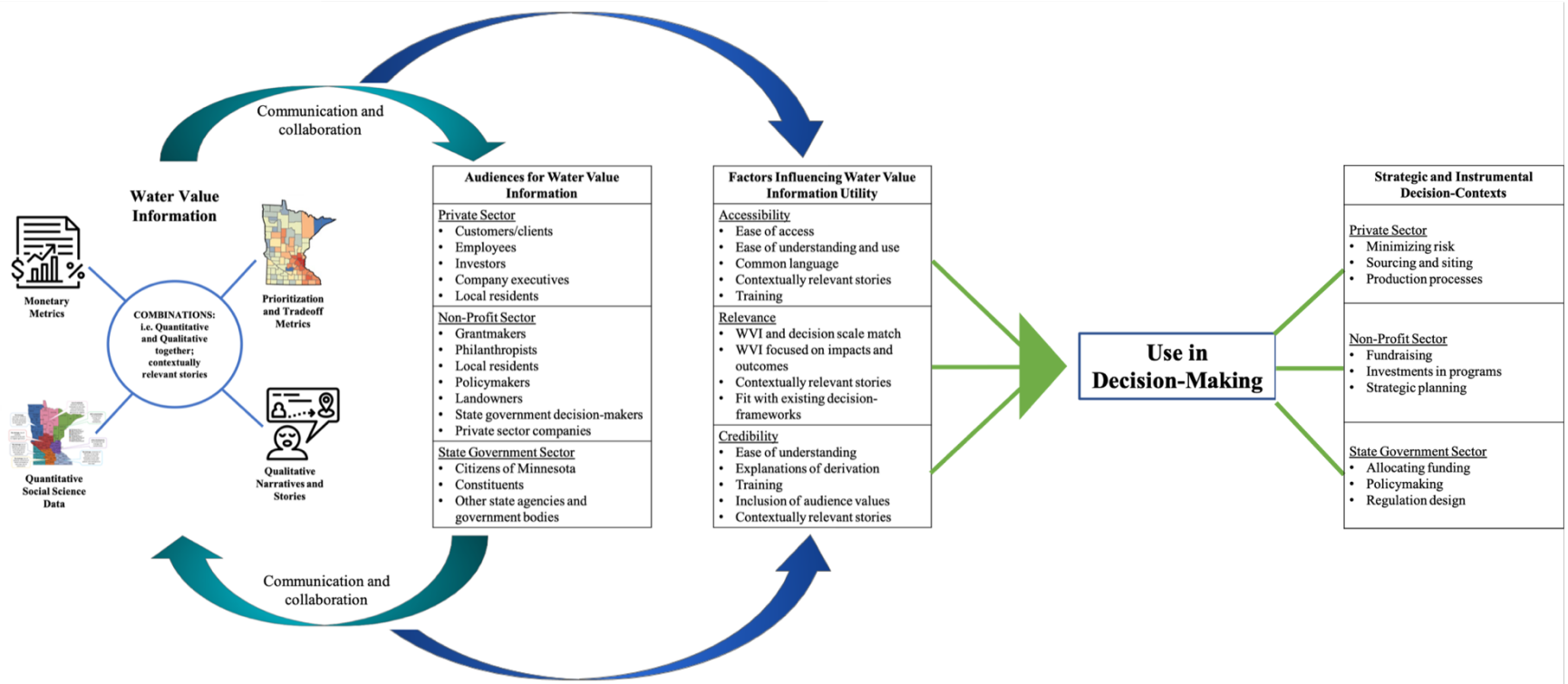

Figure 5 Integrating Water Value Information into Decision-Making Framework: *Types of water value information have greater utility when used in conjunction and when there are strong collaboration and communication pathways between water value information creators and its intended decision-making audiences. Strengthening these pathways increases the utility of water value information for all sectors because it increases the accessibility, relevance, and credibility of the information. When water value information is accessible, relevant, and credible, it is more likely that decision-makers will use it in strategic and instrumental decision-making contexts that are more likely to have positive impacts on water-related ecosystem services.* *(Monetary Metrics image: "Monetary Policy" created by Massupa Kaewgahya from Noun Project; Qualitative Narratives and Stories image: "Storytelling" created by Nithinan Tatah from Noun Project)*

Discussion and Conclusions

The purpose of this research was to better understand the factors that make water value information easy or difficult to incorporate into decision-making in hopes of learning how to increase the influential power of water value information in diverse decision-contexts. I hypothesized that water value information needed to be easy for decision-makers to access and use within existing decision-frameworks for it to lead to changes in decision-making. My findings suggest this is the case and highlight issues of accessibility, relevance, and credibility as key leverage points for increasing the utility of water value information. However, my findings also show that competing priorities, power dynamics, and the importance of securing revenue streams are also key determinants of whether decision-makers will consider water value information in decision-making.

The findings from my research demonstrate that the business as usual approach to researching and communicating water value information falls short of the needs of decision-makers; water value information lacks utility and relevance in many decision contexts because it is often hard to access, difficult to understand or use with available resources, lacks credibility and legitimacy, and lacks relevance to decision frameworks. These findings are paralleled by previous work that tells us the salience of information—its ability to meet the needs of decision-makers—is indicative of its effectiveness (16, 30). Various studies have found that ecosystem service information is less frequently used in decision-contexts which require a greater investment of time and resources to incorporate the ecosystem service information (11, 14, 17-18), when the amount or complexity of the information is overwhelming (14, 30), or when the scope, scale, or value-focus of the ecosystem service information does not match with the way decisions are made (11, 14-15, 18, 30). My findings support this while also highlighting an institutional gap in water value information science: there is no single, streamlined, vetted database of water value information that takes the sheer amount of information available and translates it into actionable information. This is a crucial piece that is missing from the discipline and that interviewees felt would help overcome issues of accessibility. This work demonstrates that water value information remains disjointed from many decisions

because our economic systems and accounting frameworks do not make room for its consideration and continue to prioritize short-term gains over long-term benefits of natural capital as previous work has also suggested (11, 15). The resulting irrelevance of water value information to decisions is exacerbated by the fact that decision-makers demand information that is more focused on potential impacts—not just risk—that are tangible, smaller-scale, shorter-term, and more certain than water value information currently provides (14-16, 18, 30).

Ecosystem services practitioners and science communications researchers alike have found that trust of both science information and scientists themselves are key determinants of whether or not information will be used and acted on (16, 30, 32-35). Decision-makers and their audience both need to trust the methodology behind the generation of water value information and view it as unbiased and respectful of their values for it to be useful in multiple decision-contexts. Science communication theory argues that scientists are more likely to lose the trust of their audience and their results are more likely to be questioned or considered biased when presented in a way that favors specific values, policy outcomes, or political perspectives and that people are more likely to dismiss information if they feel it poses a threat to other things they value (32-34). This suggests that the issue with water value information may not be only about the characteristics of the information itself, but also a factor of how it is communicated, who is communicating it, or who is included in the water value information creation process. Decision-makers I spoke to shared that contextually relevant stories can help counteract this feeling of being threatened because they come from trusted members of the audience the decision-makers are targeting and use quantitative information to further strengthen the validity of the stories.

This research shows that decision-makers mainly use water value information for raising awareness and setting priorities, two decision-contexts which require less time and resources and have lower reliability and accuracy requirements for information to be useful and relevant (Figure 6) (17, 36). However, the factors that make water value information costly or difficult for decision-makers to use outside of these decision-contexts have significant implications for the impact and therefore value of water value

information. Conceptual and strategic uses of ecosystem service information to change perspectives, raise awareness, build support for actions, or set priorities are not only the more common uses of ecosystem service information, but they are also the use pathways that have been found to have less impact on ecosystem services and natural resource protection (16-19).

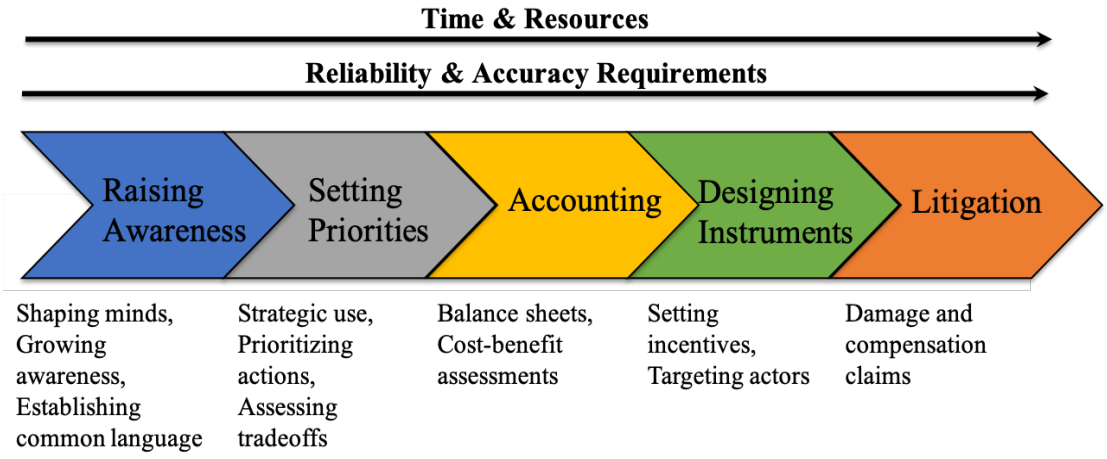

Figure 6 Information and Resource Requirements by Decision-Context: *Using information in different decision-contexts requires varied amounts of time and other resources and different decision-contexts have a range of reliability and accuracy requirements for information to be useful. Adapted from Gómez-Baggethun et al. Ecol Econ 2013 (36).*

This suggests that water value information, although used and considered by decision-makers across sectors in conceptual decision-contexts, is not yet leading to significant impacts on water quality and water resource protection in Minnesota. Because decision-makers feel that using water value information is more complex and requires more time and resource investment than they can handle and because many people perceive water value information as inaccurate, unreliable, or untrustworthy, it has yet to become mainstream in strategic and instrumental decision-contexts which could lead to greater impact and in turn increase the value of water value information. For water value information to move up the ladder to instrumental usage pathways that generate action, produce outcomes, and increase impact on water-related ecosystem service (16-18), it is essential that water value information producers address issues of accessibility, relevance, and credibility (Figure 5).

My findings suggest that one way to address these issues is by strengthening the pathways between water value information researchers and decision-makers through improved communication and collaboration. Decision-makers told me they want water value information researchers to help give meaning to the water value information, to tell the stories behind the information, and to train them in how to better use water value information and tools. Increased communication between information creators and information users facilitates translation of information, in turn increasing comprehension, accessibility, capacity and utility of information (18, 30). Open communication channels also promote collaboration and co-development of knowledge which allows water value information creators to better understand and accommodate the scale, scope, and focus of water value information that would be useful and relevant, incorporate diverse value perspectives in water value information, and mediate differences, securing greater levels of relevance, credibility and legitimacy in the process (11, 14-15, 18, 30, 32, 35).

I also heard from decision-makers that they would like more water value information that is more focused on impact outcomes to their audiences, as that type of water value information would be more relevant to their work. Recent ecosystem service studies have come to similar conclusions: ecosystem service information that makes direct connections to impacts and human wellbeing is not only more relevant to many decision frameworks, but also is more persuasive (2, 14-15, 18, 32, 34). Furthermore, decision-makers want finer scale water value information. This contrasts with the ecosystem services theory that generalizable information would be more practical because it would be easier to use and apply in many decision-contexts; however, we are finding that general scale ecosystem service information is not always useful because it does not meet the needs of all decision-makers or the reality of all ecosystem services (11, 14). Large scale generalized ecosystem service information, such as the social cost of carbon, has been successfully applied in various decision contexts, but the success of social cost of carbon values stems from the fact that carbon-related ecosystem service impacts are experienced at a global scale over longer time periods and the benefits of taking action are easier to monetize (37). In contrast, water-related ecosystem services are extremely localized, impacts to water resources occur over various spatial and time

scales, and clean water values are diverse and not always monetizable (1, 2, 37), supporting my findings that finer scale and impact-focused water value information would be more relevant in decision-making.

I appreciate the challenges and costs associated with creating finer scale water value information, but believe it is an important avenue for further work. However, it is important to note that smaller-scale water value information could increase the complexity of the information; therefore, although increasing complexity could make water value information more relevant, it could also make the water value information less accessible (14). This paradox of wanting both finer scale quantification of water values and easy to understand narratives only increases the urgency for improved communication and collaboration; ecosystem service scientists and water value information researchers need to work in tandem with decision-makers to better understand the optimal balance between complexity and simplicity that increases the utility of water value information.

Water value information scientists not only need to increase communication pathways, but they also need to improve their communication practices. Water value information scientists should present information in a way that acknowledges and affirms diverse values, use language that does not minimize or threaten some values over others, and simultaneously be careful not to overwhelm people with more information than they can process at once (31-35). Disseminating water value information in the form of stories and narratives is one way to do this. Stories establish a common language and give context and meaning to problems that make them tangible rather than general, personal rather than foreign, and probable rather than unlikely (38, 39). Narratives can also depict the correlative relationships between actions, ecosystem service, and value in a format that allows researchers to present their conclusions about what should be done without explicitly stating their opinions on which policy outcomes are best or which values are most important to protect (38). Stories and narratives allow water value information researchers to address accessibility, relevance, and credibility in concert.

There is widespread consensus within the discipline about what needs to be done to address the shortcomings of all types of ecosystem service information, but despite

almost two decades of research telling us that we need to increase collaboration, improve communication, translate and give meaning to our results, and incorporate diverse perspectives into our work (11-19, 30), this research demonstrates that we have not yet responded to that call. The barriers which I found minimize the utility and value of water value information are the same as the challenges that have hindered the impact of ecosystem service information for years. Research institutions do not typically incentivize work that focuses on communication and translation of research or collaboration with decision-makers; as a result, academics often lack the skills to do so or simply do not see the value in making the time for this work (11). Conversely, many decision-makers still view investments in collaboration as too costly and the nature of current economic and accounting decision frameworks can prevent the outputs of collaborations from being relevant and useful (11, 15, 30). This suggests that there are larger systemic and institutional factors at work preventing water value information, and likely all ecosystem service information, from having the impact it could have on water and other natural resources. In response there is a need for future work to address these larger elements at play in addition to the specific factors affecting the value of water value information.

This work affirms that improving communication and collaboration pathways between water valuation scientists and decision-makers is a necessary part of successfully incorporating water value information into diverse decision-contexts. That said, I also found that decision-makers from all sectors place high priority on securing their funding streams. The majority of the audiences defined by interviewees are sources of revenue; interviewees shared that their decision-making processes often center around satisfying audiences in order to protect revenue streams. In the private sector, the power of revenue in decision-making was especially apparent: decision-makers are willing to take small, token actions to protect their reputation, but when it comes to larger investments in water resource protection, they need more significant monetary incentives to act due to the high risk those types of investments pose for their revenue streams, which differs from past work that pinpoints reputational risk as a lever for encouraging private sector ecosystem services protection (14, 40, 41).

The power that funding has in decision-making across all sectors results in competing priorities; I saw that even when decision-makers recognize the importance of clean water to them, their audience, or their work, they still may choose to take actions that leave out clean water considerations. This begs the question: will improving communication and collaboration between scientists and decision-makers lead to enough changes in decision-making to protect local water resources? Although all interviewees called for improved communication and collaboration, my findings also point out that the power dynamics of securing funding streams and appeasing all audiences have a strong influence on decision-making. Therefore, even if water valuation scientists are able to address issues of accessibility, relevance, and credibility by improving communication and collaboration pathways with decision-makers, it is possible that these power dynamics will still keep water value information out of mainstream decision-making (42). Further research is needed to determine which factors dominate and why organizations from all sectors are regularly not using good, high quality water value information. If they value clean water as they say they do, why are they not investing more in understanding how to use complex water value information and tools to help them protect it? Is it fully the fault of scientists that water value information is often left out of mainstream decision-making, or do the decision-makers have a role to play as well? We must study these dynamics more closely to better understand the nuances this research might have missed.

This study offers important insights into the value of water value information in decision-making and the parallels between my findings and those of past work suggest that we can extrapolate meaning from this work for decision-makers beyond the borders of Minnesota. That said, further research that asks these questions of decision-makers across a wider geographic scope and from a greater diversity of organizations in both size and mission from each sector is essential for determining the true value of water value information and achieving mainstream use of water value information in diverse decision-contexts.

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Appendices

Appendix 1 -- Interview Protocol

Value of Water Information Research – Interview Protocol

Before we begin, I would like to state that I will assume you are speaking on behalf of your professional self and the organization you represent with your responses to these questions.

Section 1

First, I'd like to begin by asking you about your organization and your role there.

1. In your own words, would you briefly describe the mission of [organization name]?
2. Tell me about your role within [organization name].
3. Who are the key audiences [organization name] serves?
    a. What matters most to them? How do you report or communicate your work back to these audiences?

Section 2

Now, I'd like to talk with you about [organization name]'s work in regards to water, particularly the social and economic values of clean water.
[If people inquire about what we mean by "value" or "valuation" in the following sections → how water effects wellbeing and livelihoods of people, i.e. clean drinking water, recreation, spiritual, etc.]

4. In what ways does your organization use water or engage in water resource issues?
5. How important is clean water to your organization?
    a. Please explain.
6. You've described several clean water "values" or "benefits." Which of the ones you mentioned would you say are most important to your organization?

a. How do those values influence your organization's work?

Now I'd like to get your thoughts on the different types of water value information and how it might be used in your work.

7. What types, if any, of water resource data or information does your organization use in its work?

8. Are there types of water resource data or information that you don't have access to that could contribute to your work? Please explain.

9. Research at the University of Minnesota and elsewhere on water valuation has developed tools for water decision makers that help them better incorporate the value of clean water in their work. [*Examples of products of this work include: estimates of the economic value of water protection, maps that show biophysical and socioeconomic risks to water, spatial visualizations of different land use decision trade-offs, and narratives about values that are difficult to quantify such as cultural or ecological values.*]

   a. Have you had any experiences with water valuation tools or products? If so, what types? Please explain.
      i. How did you use the valuation tools or products?
      ii. Were they helpful in your work? Please explain.
   b. I'm interested in your perspective on different types of information on the value of water. I've got a few examples I'd like to share with you. [*Monetary metrics, prioritization metrics, quantitative social science data, qualitative narrative and storytelling data--interviewer presents visual examples of each type of information to the interviewee*]
      i. How would monetary metrics of water value be useful in your work?
      ii. How would prioritization metrics about tradeoffs for different decisions be useful in your work?

iii. How would quantitative social science survey data be useful in your work?
iv. How would narratives and stories about water be useful in your work?
v. Besides these, can you think of any other type of information on water values that could be useful in your work?

10. Information on water values can inform decisions in different contexts. Of the following decision-contexts, where do you see information on the value of water being most useful or relevant in your organization's work [*choose 1-2 below*]?

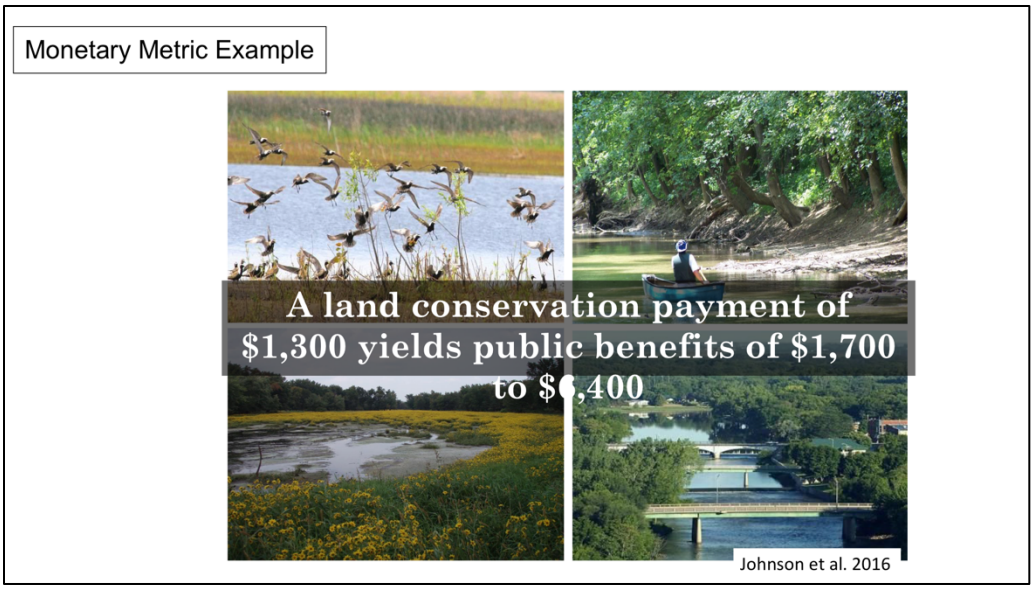
a. Raising Awareness (shaping minds, growing awareness, establishing common language)
b. Setting Priorities (strategic use, prioritizing actions, assessing tradeoffs)
c. Accounting (balance sheets, cost-benefit assessments)
d. Designing instruments (setting incentives, targeting actors)
e. Litigation (damage and compensation claims)

11. For your organization, what are the biggest barriers to incorporating information on water values into these decision-contexts?

a. What additional resources or expertise would make it easier to incorporate this information in your work?

12. Is there anything else you would like to share with me about water values or water value information before we conclude?

Appendix 1.1 -- Images used with Interview Protocol Question 9b



Monetary Metric Example

Costs of Well Contamination

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Crop switch could cost millions in water contamination

Mark Steil · Worthington, Minn. · Jul 10, 2014 — Environment

The number of southeastern Minnesota household wells that are contaminated with potentially dangerous nitrates could increase by nearly 50 percent in coming years, a University of Minnesota study shows.

Plowing *MPR Photo/Mark Steil*

The potential problem stems from high grain prices in recent years that led farmers to convert grasslands to plowed fields, said researcher Bonnie Keeler, lead scientist at the university's Institute on the Environment. It could force homeowners and local governments to spend millions of dollars to treat their water, the report said.

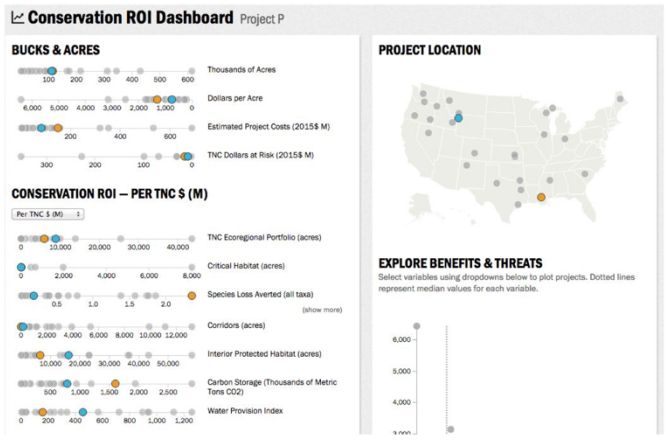
• **Beneath the Surface, a special Ground Level report**

	Initial costs	Annual costs
Reverse osmosis	$300-1,300	$100-300
Distillation	$250-1,500	$400-500
Anion exchange	$600-2,200	$84-144
New well	$7,200-16,000	-
Bottled water	-	$529-1,959

Keeler and Polasky ERL 2014

Prioritization Metric Example

Return on Investment Dashboard Tool



Prioritization Metric Example

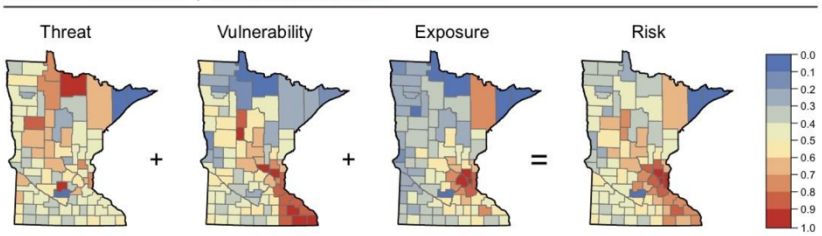
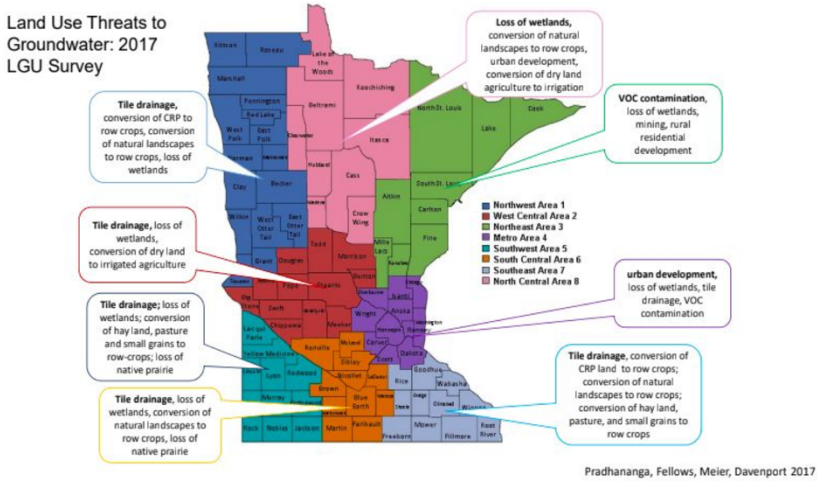


Fig. 2. Spatial heterogeneity in N-related damages. Damages are associated with groundwater NO_3^- contamination where the risk of damages is estimated as the sum of NO_3^- threats, vulnerability, and exposure. Threat is represented here as the risk of row crop expansion, calculated as the percent change in fertilized acres of cropland between 2007 and 2012 (*60*). Vulnerability is estimated from soil and geologic characteristics that facilitate the transport of NO_3^--enriched runoff and increase the susceptibility of aquifers to contamination (*51*). Exposure is quantified as the number of households in each county that rely on self-supplied groundwater, normalized by county area and log-transformed (*48*). All indices were normalized on a 0-to-1 scale.

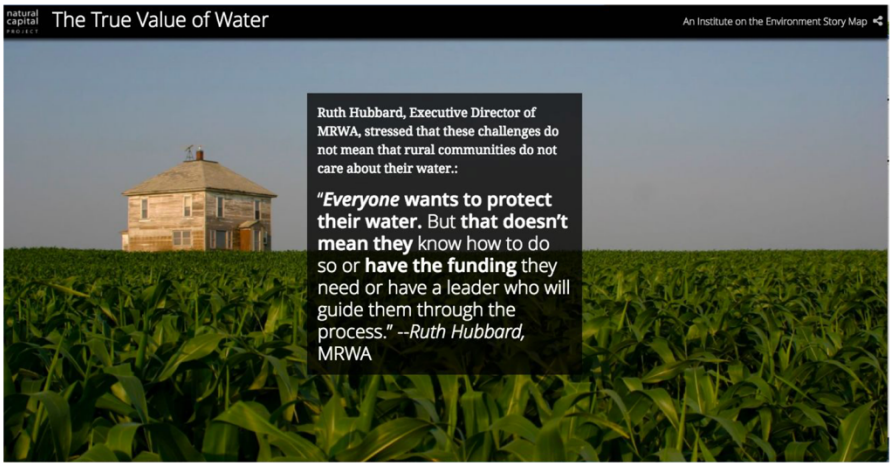
Keeler et al. 2016 Science Advances

Quantitative Social Science Example



Pradhananga, Fellows, Meier, Davenport 2017

Qualitative Narrative Example



Appendix 2 – Codebook

Code	Description
Decision-Making Theme	KEY THEME: Organizational tier code. Where will knowledge on the value of water lead to the most change? This theme represents our research question that aims to shed light on how organizations from different sectors makes decisions, how information is used in decision-making and how information can influence decision-making. Codes under this theme include codes for how information on water value is used-- in what decision-contexts is it relevant, influential, (and therefore valuable) for organizations.
accounting	use when interviewee mentions that their organization uses information on water values in their accounting processes and decisions, cost-benefit analyses, return on investment, etc.
capacity	use when interviewee expresses anything related to their capacity or ability to include water value information in their decision-making processes (time constraints, ease, etc.)
challenge_barrier	use when interviewee points out specific challenges or barriers to including water value information in their decision-making processes
communication	use when interviewee refers to ways they communicate with their audience or when interviewee mentions that their organization uses information on water values for communication with their audiences
cross-sector collaboration	use when the interviewee mentions collaborations with other organizations that are in a sector other than theirs
decision-making	use when interviewee is discussing decision-making practices, processes, influences, etc.
designing instruments	use when interviewee mentions that their organization uses information on water values to design instruments, set incentives, or target specific actors
efficiency	use when the interviewee expresses that efficiency is an important consideration in their organization's decision-making processes
facilitator	use when interviewee discusses anything that does or would facilitate including water value information in

Code	Description
	their decision-making processes
impact-outcomes	use when the interviewee expresses that the impact of the decision is an important consideration in their decision-making processes
litigation	use when interviewee mentions that their organization uses information on water values for litigation
policy	use when the interviewee expresses discusses implications of policy to their work; this code includes legislations and regulations, policy-making, etc.
raising awareness	use when interviewee mentions that their organization uses information on water values to raise awareness, either within or outside of their organization
responsibility	use when the interviewee expresses that the organization is or feels they have a responsibility or accountability towards water resources, water protection, water conservation, etc.
risk	use when the interviewee expresses felt risks or threats to their organization or audience related to water and water values
setting priorities	use when interviewee mentions that their organization uses information on water values to set priorities for how they work, where they invest, etc.
solutions	use when the interviewee expresses that their organization considers whether the decision can or will solve a problem
technology and innovation	use when interviewee mentions that their organization uses information on water values to create new technology or encourage innovation within their organization
within-sector collaboration	use when the interviewee mentions collaborations with other organizations that are in the same sector as theirs
Quote	Use this to mark passages that may make good quotes in the reporting of our research.
Value of Information	KEY THEME: Organizational tier code. What types of information on water value are most useful or relevant to different sectors and in different decision-contexts? This theme represents our research questions about the value of information through codes that highlight where

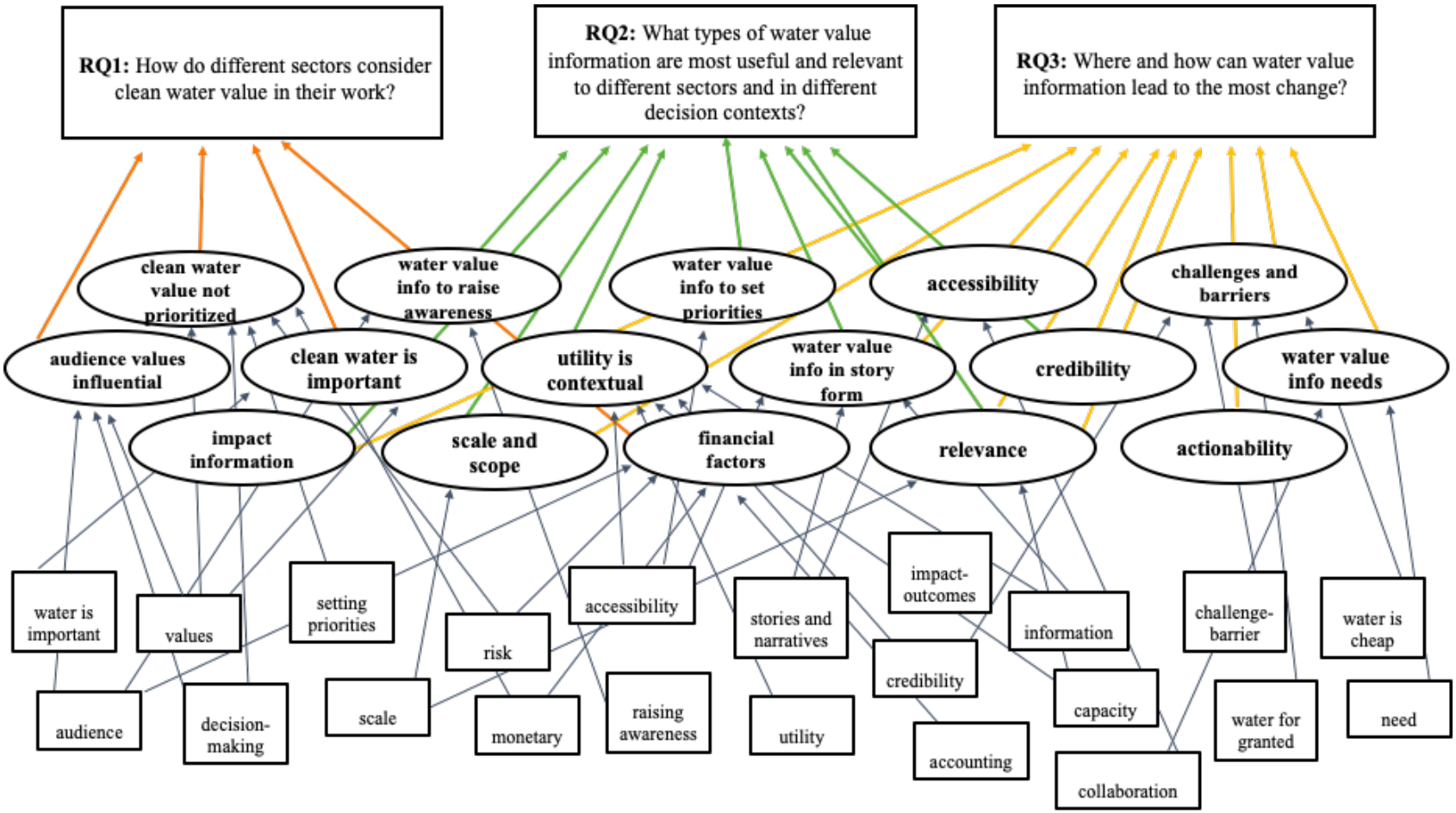
Code	Description
	interviewees discussed the usefulness of information, the relevance of information to their work, the types of information that are useful or relevant, where they get information, where they lack information or access to information.
accessibility	use when the interviewee is discussing the usability of information-- does information make sense to their audience, how is the information presented, is it accessible to them, is it understandable, usable, etc.
credibility	Use when interviewee expresses any issue related to perceptions of credibility, trust, reliability, etc. of or in certain types of data or information
information	Use when interviewee is talking about information, which includes: knowledge, facts, stories, can also include data as a type of information, any knowledge the organization uses or considers in their work and decision-making; explicit references or use of the term "information"; summary reports even if the reports are based on data, qualitative or subjective ideas/beliefs/findings, etc. Differs from data in that it is not specifically numerical and measurable
data	use when interviewee is talking about numerical, measurable information, which we are going to call data. Sometimes there will be instances where data and information show up together in a passage, as someone is using both numerical and other information in their work. This code is used when people use measurements or numerical standards to set priorities or goals, very quantitative in nature
metrics	Use when interviewee is discussing various types of metrics
need	Use when interviewee mentions that they do not have access to certain types of data or information or that they do not believe a certain type of data or information exists that they think would be helpful to have, or that what is available/what they have access to is not exactly what they need
qualitative	Use when interviewee is discussing qualitative information
quantitative	Use when interviewee is discussing quantitative

Code	Description
	information
scale	use when interviewee is talking about the scale of information or data
standards	Use when interviewee is discussing anything related to water quality or quantity standards information, monitoring, data, standard-setting, etc. -- defined statutorily; things such as TMDLs, contaminant concentration targets, etc.
stories and narratives	Use when interviewee is telling a story or use when interviewee expresses that stories about water are useful or are a part of how they think about water
utility	Use when interviewee is expressing the utility of a certain type of information or data to their organization
un-useful	Use when interviewee says data or information is un-useful and/or irrelevant
useful	Use when interviewee says data or information is useful and/or relevant
Water Values	KEY THEME: Organizational tier code. How do organizations consider water values in their work? This theme represents all codes that relate to water values expressed by interviewees. Whose values organizations consider, time and space components of values, and types and dimensions of water values
affordability	Use when interviewee is discussing whether or not water is affordable, if access to water is affordable for them or for others
audience	Use when interviewee mentions any groups that the interviewee identifies as their audience, who their organization serves
downstream	Use when interviewee is talking about downstream water values, water issues, water impacts, etc. that factor into their organization's consideration of water; use if interviewee specifcally uses the word "downstream" or refers to the idea that what we do to our water resources where we are has an impact on water resources elsewhere
drinking water	Use when interviewee specifically mentions drinking water

Code	Description
farming_agriculture	use when interviewee mentions anything about farming or agriculture
future	Use when interviewee expresses consideration of water for the future, for future generations, for future water needs, etc.
global	Use when interviewee is talking about global water values, water issues, water impacts, etc. that factor into their organization's consideration of water
human health	use when interviewee mentions human health
local	Use when interviewee is talking about local water values, water issues, water impacts, etc. that factor into their organization's consideration of water; local meaning where their business is based, local meaning Minnesota
Minnesota	Use when interviewee expresses the idea that water as something that is Minnesotan, that it is part of the Minnesota identity, that there is a Minnesota water ethic, mentions that Minnesota is the land of 10,000 lakes, etc.
monetary	Use when interviewee references monetary costs or benefits, economics, finances, etc.
present	Use when interviewee expresses consideration of water for the present, for current generations, that it is important to think about water now, etc.
protection	use when interviewee is talking about water resource related protection activities, actions that help protect a resource as it is, prevent (further) degradation, etc.
restoration	use when interviewee is talking about water resource related restoration activites, actions that bring a natural enviornment or resource back to a more pristine state
social-cultural	Use when interviewee references cultural or social factors such as spiritual connections, recreation opportunities, community importance, historical importance, identity, etc.
tradeoffs	Use when interviewee is expressing that there are tradeoffs between the values that they consider in their work; the idea that you can't protect all the values equally and so you have to think about which are most

Code	Description
	important, how to prioritize, etc.
values	Use when interviewee expresses values: things that matter to them, things they consider, when they say things such as "we care about" or "we consider", when an interviewee reflexts commitment, support, care, emphasis, concern, that is going to be connected to a value, value-based action, how values influence their goals and mission
water is cheap	Use when interviewee expresses that the cost of water is low or cheap; this is not about whether or not it is affordable, but more about the idea that water is undervalued, that it is underpriced, that the price of water is so low that it is a disincentive to act to protect water let alone to even be aware of your water usage
water is important	Use when the interviewee mentions that water is essential to the success of the organization, to what the organization does. It is a key input or key output or key component of the organization's work, when they say that it is very important
water is taken for granted	Use when interviewee specifically says that water is "taken for granted", or when interviewee expresses the idea that society does not fully appreciate the value that water resources provide
water quality	Use when interviewee mentions anything related to the condition of water or a water resource (not amount of the resource). Any issues, values, thoughts, consideration of topics related to water quality or water quality standards or metrics such as, clean water, water pollution, chemical, physical, biological characteristics of water
water quantity	Use when interviewee mentions considerations of water quantity : how much water is being used, measuring water use amounts, minimizing water use amounts, being conscious of water use amounts, etc.

Appendix 3 – Analytical Mind Map



Analytical "mind map" model we used to connect codes (bottom) and emergent themes (middle) to search our data for prevalent themes, divergence and convergence across sectors. We then used this map to see how the prevalent themes we found converged to provide insights into our three research questions (top).